

SHATTUCK

Acoustics of Audience Rooms

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ACOUSTICS OF AUDIENCE ROOMS

BY

WALTER FRANCIS SHATTUCK

THESIS

For the Degree of Master of Architecture

COLLEGE OF ENGINEERING ✓
UNIVERSITY OF ILLINOIS

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June 1. 1908

THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

Walter Francis Shattuck

ENTITLED Acoustics of Audience Rooms

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Master of Architecture.

N. Clifford Ricker

Instructor in Charge.

APPROVED:

N. Clifford Ricker,

HEAD OF DEPARTMENT OF Architecture

1908



ACOUSTICS OF AUDIENCE ROOMS.

The application of the principles of acoustics to audience rooms is not as well understood as it should be if we may judge by the results produced. The theory of sound has been pretty well worked out but the difficulty lies in the applying of the principles to the endless variety of sizes, shapes, materials and details of different buildings.

Some profess great faith in the proportions of the room, others in the shape and contour of the enclosing walls, and still others in the materials of construction or ornamentation.

I will classify the audience rooms in two ways - First - as to their use. Second - as to whether their size and form makes sound reinforcement necessary. Under the first classification we have three types of rooms: first, the concert room, where the orchestra or speaker is placed or should be placed in the sound focus and where everything is subordinate to the auditor; second; the theatre where there are two sound foci - one for the orchestra and one for the actors; and third, the hall for deliberative assemblies. This classification is quite an arbitrary one but I consider it best for the discussion of the subject.

The order in which I will discuss the different parts of the subject will be as follows:

- 1.- Principles of sound transmission.
- 2.- Plan and form of Audience Rooms.
- 3.- Plan and form of Assembly Rooms.
- 4.- Ventilation, Heating and Lighting of Audience Rooms.
- 5.- Sound reenforcement of Audience Rooms.
- 6.- Correcting acoustic defects in Audience Rooms.



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The literature on the subject of the acoustics of audience rooms is somewhat limited: the two really valuable books being "Acoustics of Public Buildings" by T. Roger Smith, and "Acoustics" by Eugene Henri Kelly. Unfortunately both of these books are out of print and there seems to be no probability of new editions being issued. There have been many magazine articles written which are very interesting, though not always conclusive.

PRINCIPLES OF SOUND TRANSMISSION.

PROPAGATION.- Propagation of sound is the physical or mechanical method of causing air to assume vibrations consisting of regular and irregular air waves. It is said by many that sound travels in straight lines but this is hardly true as the waves are more spherical in form, or better still they are ellipsoidal. When the sound is conducted through a tube, a cone or the mouth of a speaker the waves are egg-shaped with the large end of the egg opposite the tube or speaker.

HEARING.- Hearing is the action of the air on the tympanum of the ear; its conductive power to the inner ear and its final transmission to the brain. The divided result of hearing is noise, sound and tone; their difference being due to the form, composition and volume of the air waves in vibration.

NOISE.- Noise is an explosion or concussion of air, having irregular and uneven air waves in form, volume and composition.

SOUND.- Sound is a graduated vibration of air waves in volume, number and composition, and possessed of the qualities of Dead, Harsh, Cold, Rich, Warm, Pure and Live Sounds.

TONE.- Tone is a periodical vibration of air waves having for

its component parts - Duration, Pitch, Volume, Timbre, Life and Lustre.

MUSIC.- Music is a combination of tones set to characters which represent melody, harmony and dissonance.

MELODY.- Melody is an agreeable succession of rhythmical single tones, individual, in order of propagation and creating a musical theme.

HARMONY.- Harmony is the simultaneous propagation of two or more tones; the number of their vibrations having a common divisor; a combination of tones that are agreeable to the ear.

DISSONANCE. - A dissonance or discord is the simultaneous propagation of two or more tones, the number of their air vibrations not having a common divisor. For example - Odd and even numbers in unison; as the pitches of C and D on the piano uttered simultaneously.

REFLECTION.- Sound waves rebound or reflect from a hard or smooth surface, the angle of reflection being equal to the angle of incidence only when the angle is greater than 45°. When the sound waves or vibrations strike at an angle between 45° and 30° they are not reflected at a perfect angle and when striking at an angle less than 30° they are not reflected at all but are conducted along the surface of the object in the same way that a water wave striking against a bank at a very acute angle glides along it instead of being reflected by it. To the power of reflection is due most of the disturbing phenomena of acoustics.

Sound waves reflected from a curved surface or wall tend either to condense or focus at or near the center or focus of the curve or to reflect in parallel lines according to the curvature of

the surface and to the location of the sound propagation or point of issue. See figures 1 and 2.

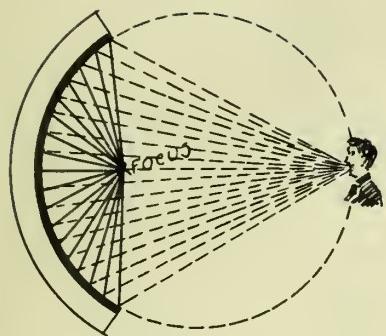


Fig. 1.

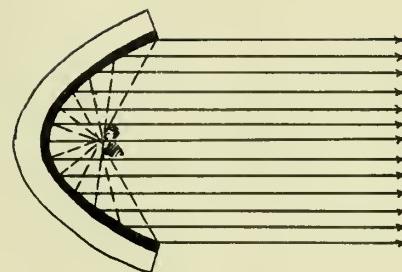


Fig. 2.

NODE.- A node is a location of silence on a bisecting angle between the angle of contact and the angle of reflection and is always at right angles with the surface at the point of sound contact.

ECHO.- An echo is a returning sound wave having an intervening silence between it and the next outgoing primary sound wave.

See Fig. 3.



Fig. 3.

Many writers claim that an echo

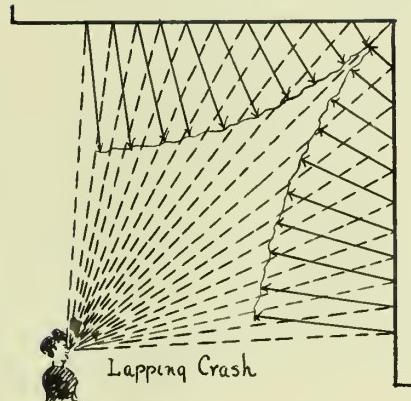
can not occur when the reflecting surface or wall is less than 112 feet from the point of propagation of the sound, but I do not find this to be true in all cases. I have obtained an echo when the reflecting wall was but about 50 or 60 feet from me. I agree with Mr. Burrow that if you take the difference between the direct path of the sound from the speaker to a hearer, and the length of the reflected path - supposing that the sound was reflected from a wall to the same hearer - and found them to dif-

fer by more than 40 feet; an interference from echo was perceptible, and when it became a little more than 40 feet, was very perceptible; consequently in a room no more than 20 feet across, a man might hear the echo of his own voice.

REVERBERATIONS.— Reverberation is an echo or series of echoes within too small a compass to be clearly heard as an echo and occurs when the reflecting walls are close to the speaker.

CRASH.— A crash is an echo and a primary sound wave in collision without an intervening silence; also a lapping collision between two returning waves at the junction angle of a room. See Fig. 4.

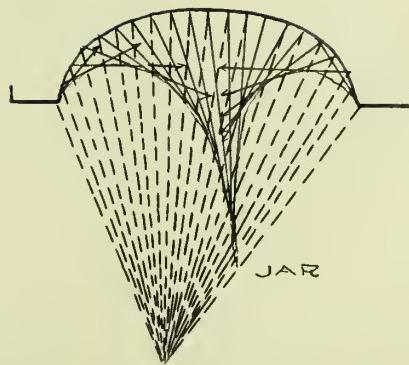
Fig. 4.



JAR.— A jar is a returning sound wave from any concave dome or circular angle focusing and lapping on a primary wave. Jars always focus at or near the generating point of the circular reflecting surface. When the jar is the result of a sound wave returning from a continuous circle corner it is called a wedge.

See Fig. 5.

Fig. 5.



FLUTTER.- A flutter is a primary sound wave in contact with a circular wall or ceiling when the point of sound issue is at the side of or on a tangent to the reflecting surface. See Fig. 6.

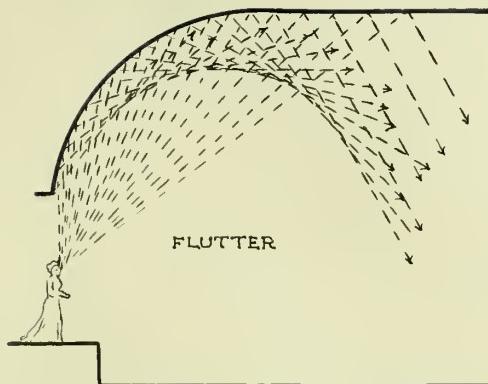


Fig. 6.

RESONANCE.- Resonance is the flexibility of sound waves or the property enclosed air pockets possess of continuing vibration after propagation of sound ceases. Resonance and sound reinforcement are one and the same thing, sound being capable of reinforcement by means of setting up a vibration in bodies which will vibrate to the same note.

DEFLECTION.- Deflection is due to spreading again of waves of vibration after they have passed some obstacle in their course. For instance if a large building intervenes between you and the point of issue you may not hear the sound if you are close to the building, but if you get further away the sound becomes audible as the waves spread out again after passing the obstruction.

REFRACTION.- Refraction is the bending of the sound waves when they enter a different medium in much the same manner as light is refracted.

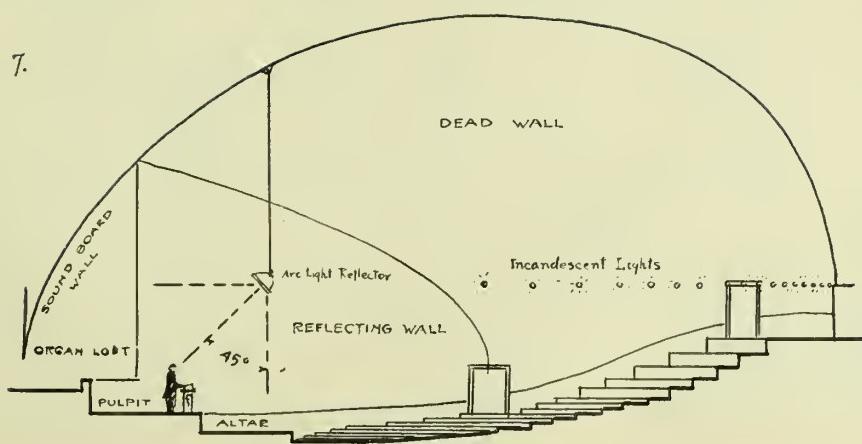
ABSORPTION.- Sound is absorbed when it strikes a soft and yielding substance, the degree of absorption depending upon the nature

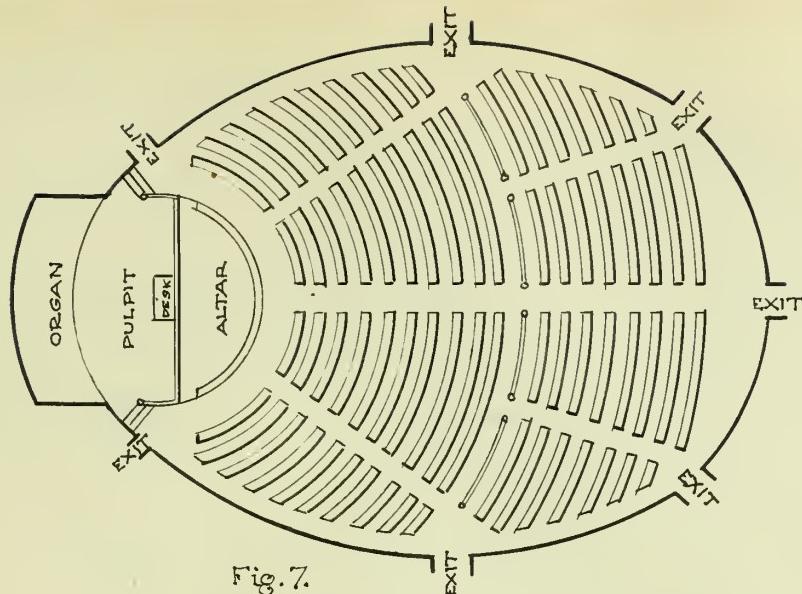
of the substance. Velvet and other tufted fabrics absorb a great deal of sound. Professor Sabin, in experimenting with different substances, found that hair cushions were the best absorbants and that it made little difference whether the leather surface of the cushion were uppermost or the cloth surface. In an audience room the chief absorbants are the clothes of the audience, the upholstery of the seating, the floor covering and the hangings or draperies.

PLAN AND FORM OF ROOM.

There is a great diversity of opinion as to the proper form of the room. There is a difference of opinion as to the limits of distance to which an average voice can be heard. H. W. Burrows claims 90 feet in front of the speaker, 75 feet on each side, 30 feet to the rear and 45 feet vertically. Eugene Kelly and Saunders give about the same proportions, while Sir Christopher Wren gives the limits as 50 feet, 30 feet and 20 feet. The theoretically correct room would then be the room whose proportions would correspond to those dimensions, as the sound would reach all of the enclosing walls at the same moment and if reflections took place there would not be nearly the tendency to troublesome confusions. Kelly considers that a perfect egg is the ideal form for an audience room, as shown by plan and section in Fig. 7.

Fig 7.





the longitudinal axis of the oval being on the level, the seating occupying the lower part of the oval and the curved side walls and ceiling the upper part. He avoids the often made criticism of the reflection of the sounds from the audience to the focus where the speaker is located. The whole rear wall and ceiling surface being dead or absorbant can not give rise to any of defects known as echoes, reverberations, jars or flutters. The reflecting surface of the walls close to the speaker reinforces the sound waves, but so reflects them that they will not become confused with the primary sound waves.

Kelly classifies all floor plans for their acoustic value as shown in Fig. 8

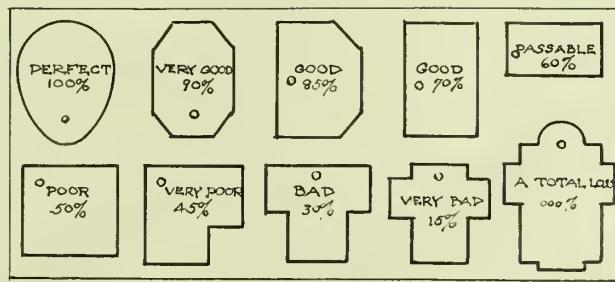


Fig. 8.

but in condemning certain of the plans he fails to state that they may be very good acoustically if their side walls and ceil-

ings are properly constructed.

John Faxon offers the following rule for proportioning the plan. Inscribe an area with a circle having a radius of 60 feet, place the phonic center or speaker 30 feet from the periphery.

A church built by John Stevens of Boston, and acknowledged to be acoustically perfect, is of the following proportions: Length 150 feet, Width 80 feet, Height 35 feet; Side gallery 11 feet wide; Rear gallery 14 - 0" deep. Dr. Brewer claims that the length of the room should be about two-thirds greater than the breadth so that the sound reflected from the side walls will assist the primary sound waves, and that the height should somewhat exceed the breadth.

Many make strong claims for the harmonic proportions.

Fletcher claims that for good acoustic properties a building should be so constructed that its different dimensions shall be in some simple ratio, such as 1 to 2, or 2 to 3, or 3 to 4. Further in the case of three numbers, a harmonious proportion exists; thus 2, 3 and 6 are in harmonic proportions. There are many examples where different harmonic proportions carried out in proportioning rooms have produced good results, but I think that the value of the proportion is much exaggerated. For instance one writer claims that he was called upon to correct the acoustics in a room, and upon measuring he found that the room was not harmonically proportioned, but by putting in shelving all over one side of the room and filling the shelves with books he cured the defect. The statement is wrong for the defect was reflection of sound waves and was remedied by breaking up the wall surface with books and not by shortening the room one foot.

The shortening or lengthening of a room by a small amount can have no effect on the acoustics except in so far as you change the reflections. There are many cases quoted where the same dimensions in two different rooms gave entirely different results, so that I have come to the conclusion that every room is a problem by itself and that it is not so much a question of plan as of breaking up or controlling the reflected sound waves.

CONSTRUCTION AND MATERIALS.

It will be conceded by all that upon the selection of the proper materials for the construction and decoration of buildings their acoustic properties greatly depend, but we will first consider the form of the walls and ceilings. In simple rectangular rooms the great danger is from the reflections from the side walls and end wall and angles. A large cove joining the side walls and ceiling usually increases the defects rather than obviating them. To overcome the defects due to the rectangular form, break up the side walls with projections in the shape of architectural features. The only limit to these projections is that they must not be so deep as to form resonance pockets. The rear wall may be broken up by the use of a balcony or if a balcony can not be used, the upper part of the rear wall may be made a non-reflect- or, and the lower part a series of openings which open onto an arcade or loggia. There are several instances where the removal of the gallery from an audience room has ruined acoustically a room which was previously perfect, and also where the install- ing of a balcony has wonderfully improved an imperfect room. One case is given by Mr. Smith where lowering of the slope of the seating in an audience room spoiled the acoustics of the

room altogether.

The ceiling if flat and a reflecting surface should be broken up by beams or panels so as to break up the reflections. The angles of the room adjacent to the speaker should be cut off at 45° so as to avoid the danger of a flutter. The speaker should not be placed in the corner but in the center of the end of the room with his back to a flat wall and not over 15 or 20 feet from the wall. Do not place a curved wall back of him unless it is non-reflecting, as it is liable to condense the sound and produce defects unless it is carefully proportioned for a sounding board. In the Art Institute of Chicago it was found necessary to have such a wall with heavy plush draperies hung in heavy folds. An ellipsoidal or spherical dome in the ceiling is very dangerous if it is deep. It may cause very annoying reverberations. If the use of the dome is unavoidable, the surface should be heavily ribbed or coffered so as to break up the sound waves, or a cornice around the edge of the dome will sometimes break up the waves.

As to the material of which the side walls and ceiling are constructed there is much difference of opinion, due, I believe, as to whether resonance is desired or not. Resonance is a difficult subject. We are all familiar with how startlingly distinct is the sound of our voices in an empty house in which there are no draperies, carpets or furniture, and how the dropping of a hammer will send the echoes and reverberations ringing through the house and how greatly these are assisted if the floors are of marble or tile and if the walls are of smooth hard plaster or marble. If we return to the house after the rugs, draperies and

furniture are in we are surprised to find no echoes or reverberations, all having been absorbed.

In an audience room where music is to be heard to the best advantage a resonant wall is desirable as it gives off sympathetic vibrations which greatly increase the beauty of the music.

A room lined with wood will give the greatest amount of resonance and there are many successful examples of this sort of treatment. There are many examples also of rooms enclosed in solid masonry walls which have fine resonant quality. A room which is heavily upholstered and with dead non-resonant and non-reflecting side walls will be free from all echoes, but will be hard to sing in for soloists as the voice gets no assistance.

For a room which is to be used for speaking only, resonance is a dangerous thing. A small amount of it is desirable, but the difficulty is to tell when you have enough until it is too late.

For this type of room the non-absorbing side walls and rear wall and the upholstered seats and heavily carpeted floor are better. The audience itself absorbs a great deal of sound. This is well shown in theatres as the auditors under the gallery can not hear well as the sound is absorbed by the audience in front of the gallery and due to the form and lowness of the gallery can not be reinforced by the ceiling or the back wall.

It is a well-known fact that audience rooms frequently have a certain tone, due generally to the volume of the confined air.

A speaker should try to pitch his voice to this tone and if he determines it he will be able to speak much more easily. I saw a striking example of this in a room which I was examining with

a view to trying to cure the acoustical defects. A speaker was delivering a lecture and pitched his voice quite high. After the lecture he made some experiments for me. I asked him to lower his voice which he did and everyone was surprised to see how much better it sounded. The speaker said he pitched his voice high to overcome the defective accustics, not appreciating that he was making the conditions worse instead of bettering them.

Many writers claim that a room should be designed in certain harmonic proportions so that the enclosed air space will be of such form and volume as to have a certain tone. They usually advocate the tone of F, but this has not always proved desirable, as while a speaker may accommodate himself to and be assisted by the tone, a musical production with different tones would be injured rather than helped.

PLAN AND FORM OF ASSEMBLY ROOMS.

Halls that are used for purposes such that the speaker may be in any part of the room, such as legislative assemblies or merchants exchanges and stock exchanges, can not be made acoustically perfect, as it would be impossible to build the room so that its form would accommodate itself to every possible position of the orator.

The following suggestions would probably give the best results. Make all the floors and side walls dead to sound reflections. Construct the ceiling of the room as a sound board. Make the room as nearly square as possible, and a high room is much better than a low one. Domes over the center of the room and curved corners should be avoided, as they are liable to cause a total

failure, a well-known example of this being the Stock Exchange in London, which has marble walls and columns with a large and very deep dome over the room. They only succeeded in improving the acoustics when they hung the side walls and columns with flags and masked the dome with bunting.

The ceiling reflector should be spherical in form and so designed as to reflect all sound waves striking it vertically downward and not allow them to impinge on the side walls.

VENTILATION, HEATING AND LIGHTING OF AUDIENCE ROOMS.

Air is the familiar and natural conductor of sound. Its conductivity varies according to its density and temperature. It is generally accepted that sound travels most rapidly in a moist warm atmosphere. The drier the air, the less the conductivity. One reason why echoes are clearer in the night is that the air is charged with moisture.

Thomas Boyd gives an interesting explanation of the whispering galleries in the Capitol Building at Washington, claiming that the air is forced down the long corridors and as it enters the room it is carried up against the arches and these being cold marble the moisture in the air is condensed and forms a swirl of vapor which is held in the angle where the arch meets the ceiling and thus forms a regular speaking tube by which the sound is conducted around the room.

For successful acoustics the air in an audience room must be of an even homogeneity and as free from disturbances and pronounced air currents as possible. Any sound wave is deflected from its path by contact with a moving current of air in proportion to

the density and velocity of the air wave. Hot air waves, when undisturbed by outside conditions, rise and form ascending air currents. Cold waves under like conditions descend and form descending currents. When the outside air is in motion, say the wind is blowing 30 miles an hour, the air in the audience room will travel in the same direction as the outside air, its velocity varying according to the number of openings exposed to wind travel.

HEATING.-

It is or should be the aim of a heating engineer to so construct the heating apparatus for an audience room that in its working it will have the effect of creating the very least possible disturbance in the way of currents, draughts, or uneven homogeneity. If a large volume of hot air is introduced between the speaker and the audience, the sound wave as it issues will come in contact with the ascending current column of hot air, which will reflect a portion of its volume back to the point of utterance, deflect a portion out of its path, absorb a portion by carrying it upward, and leave only a small portion to pass thro the heated column of air to the listeners. The sound that reaches the ear of the listener is only the portion that by its flexibility, dodges thro between the crack like openings of the heated column of air. If a hot air floor register be located in a narrow corridor, the hot air column will so disturb the sound wave that all language will be almost nullified; the heat column mixing or jumbling the vowels and consonants beyond recognition, leaving the sound wave in broken form to dodge through the openings in the heat column to the listener. The installation of a success-

ful heating and ventilating plant is fraught with difficulties but if the following general principles are followed I believe that most of the defects will be overcome or reduced to a minimum. If warm air must be introduced in large quantities, it should always be introduced along the side walls, never in the body of the room. If there is a gallery and it is necessary to introduce it under the gallery, slots should be left in the gallery floor close to the wall so that the upward column can pass up along the side walls and not be forced out under the gallery and up the face of the gallery, as this will make hearing difficult both in the gallery and under it. If the side walls of a room are well heated there will be no difficulty about the center of the room. If direct heating is done by means of steam or hot water radiators, they should be placed as usual around the outside walls and those that come under the balcony should have slots in the balcony floor to permit the heated column of air to pass up. If these radiators can be direct indirect radiators the results will be better.

The ideal system of heating and ventilating seems to introduce the cold air at the ceiling through a number of small openings and it will descend by gravity. Introduce the warm air through small openings in the face of the risers in the steps that form the floor of the auditorium. The warm air rising mingles with the cold air descending. The lighter gases can be drawn off through small vents in the ceiling and the heavier carbonic gases can be drawn off by vents in the side walls near the base board, the vents having a downward direction. The volume of the incoming cold and warm air must be graduated and controlled so

that they will be in the proper proportions.

LIGHTING.

Light is naturally divided into two kinds according to the mode of propagation: Natural light, or that propagated by the sun, and artificial light. Artificial light is of two general types; those that are produced as the result of combustion and those that are the result of incandescence.

The direct effect that light has on the acoustics of an audience room is due to the creation of heated currents of air. The lights that are the result of combustion are the ones that effect the acoustics unfavorably, but fortunately the necessity for their use is becoming quite rare, as almost all audience rooms are now lighted by the incandescent electric lights. Tests made with incandescent lights show that if you hold a thermometer a foot above an incandescent light it will show no rise in temperature.

Gas lights enclosed in tubes such as globes or chimneys generate a great deal of heat. Kelly shows that a chandelier with six or eight four foot burners will give off as much heat as a direct steam radiator of 25 or 30 feet radiating surface.

Gas lights placed along the face of the balcony produce a curtain of heated air rising between the speaker and his auditors. If these lights must be used they should be placed far apart so as to leave as much unobstructed space as possible.

The placing of gas lights under the balcony is also bad unless vents are placed over them so as to prevent the heated air from passing along the balcony ceiling and out and up the face of the balcony.

The use of the center chandelier is bad as it causes a very strong air current.

Kelly well likens the gas lighting of the stage by means of foot-lights to the grate fireplace in which gas is burned. The flames of the gas form a heated current of air that covers the entire open space of the grate or stage opening. The heat current produced by the footlights ascends to a point a short distance below the proscenium arch and escapes upward through the fly gallery. The ideal lighting would be to use electric lights and so arrange them that no light shines in the eyes of anyone in the audience. Unshielded lights can be used along the back walls and under the balcony on the rear wall, also on the face of the balcony. The other lights in the audience room proper should be on the rear half of the side walls and so arranged as to be reflected forward only.

SOUND REINFORCEMENT OF AUDIENCE ROOMS.

The reinforcement of sound in audience rooms is a dangerous thing for if the room is not already free from echoes, reverberations and crashes, the reinforcement of the sound will only increase these defects. There are two methods of reinforcing the sound; by use of resonant tubes and by use of sounding boards or reflectors.

If resonant tubes are used they should be placed in the ceiling over the speaker, but if the proscenium arch is so high that they can not be brought within 12 or 15 feet of the speaker they had better be placed in a row on the stage just back of the foot-lights with their tops about an inch above the stage floor.

SOUND BOARDS OR SOUND REFLECTORS.

The transmitting properties of a sound reflector depend on two things, the material used in its surface construction and the form of its reflecting surface. For the surface construction the most desirable points are density and smoothness. In the matter of form of the reflecting surface we have three types, viz: The **plane** or flat surface and the **concave** surface and the **convex** surface. The first two are the ones generally used. The different installations of the reflectors as advocated by Kelly are as follows:

First, sound board behind speaker; all walls and ceiling dead.

See Fig. 9.

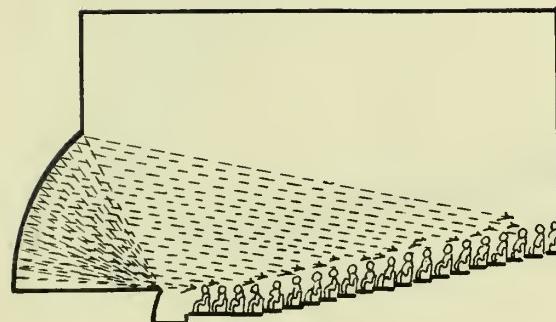


Fig. 9.

Second, Sound board behind speaker; rear wall a reflector; all other walls and ceiling dead. See Fig 10.

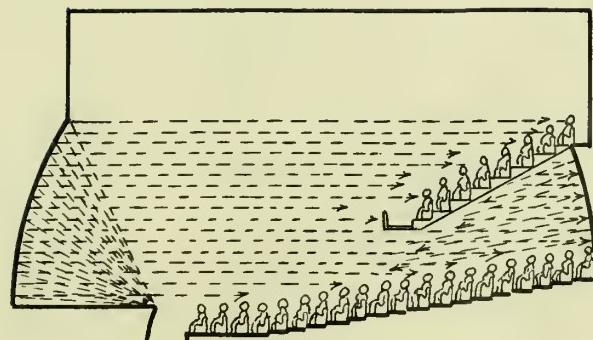


Fig. 10.

Third - Proscenium reflector; all walls and ceiling dead. See Fig. 11.

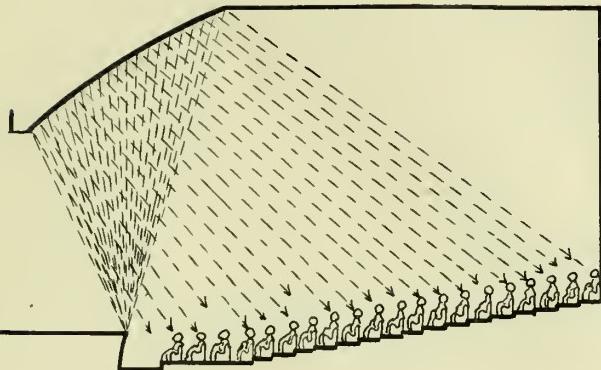


Fig. 11.

Fourth - Ceiling reflector; the rear part of ceiling and all walls dead. See Fig. 12.

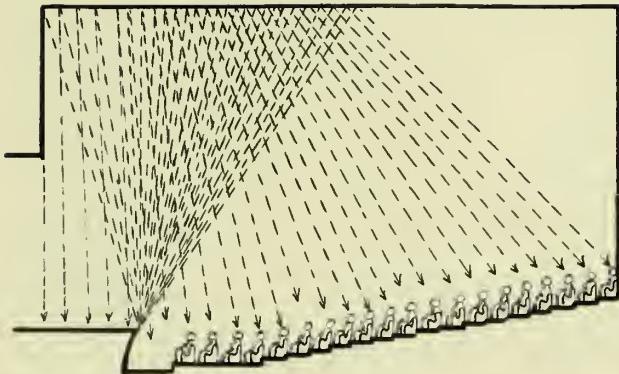


Fig. 12.

CORRECTING ACOUSTIC DEFECTS IN AUDIENCE ROOMS.

Every acoustically defective room is a problem in itself, but it is almost invariable that the first question should be, is the defect due to the reflection of sound waves or to resonance. Sometimes it is both. If the defect is due to reflections which cause echoes, reverberations, jars and crashes, the remedy is to deaden the wall or ceiling surfaces or both. The introduction of a gallery in the rear of an audience room has frequently cured the defects, as the gallery when filled with

people broke up and absorbed the sound waves. Domes are almost invariably the first things to look at with suspicion. I was called upon to examine the acoustics of a ballroom in a private house. The complaint was that they could not play the piano in the room as the sound became a mere jumble. I found a dome in the ceiling. I had the mouth of the dome covered by draping bunting in loose folds from the center to the sides and the defect was entirely cured.

I was called upon to try to correct the acoustic defects in the assembly room of St. Ignatius' College. I found this room to have about all the defects on the acoustic calendar; in fact they had almost given up using it for assemblies. The room was about 90 feet long by 50 feet wide by 30 feet high. It had a large plain ceiling cove running all around the room. There were about five high windows on each of the two long sides of the room. The rostrum was merely a large platform in one end of the room. It was about 30 feet wide, 20 feet deep and 4 feet high. The floor of the audience room was level. The side walls and ceiling were entirely unbroken by architectural treatment, the plaster was hard and smooth and painted with a gloss finish. The floor was uncarpeted and the seats polished and not upholstered. One of the priests spoke for me when the hall was empty and I found it unbearable, due to the pronounced reverberations and resonances. I suggested that we experiment with cheesecloth hung on the rear wall in loose folds and about an inch out from the wall, also that a curtain about 5 feet deep be hung from the ceiling so as to shield the entire rear cove, and that a similar curtain be hung across the ceiling in the center of the room. All of this was

done except the ceiling curtain in the center of the room. I next visited the room when an assembly was being held. A lecture was being given illustrated by the stereoptican. The speaker stood in front of and to one side of the curtain. The acoustics were much better but still not what would be called good. It was too dark for me to see what the speaker was standing on, but I noticed a disagreeable resonance and also that he had pitched his voice too high. After the lecture the speaker made some experiments for me. He first pitched his voice down and we found that we could hear better and he found that he could speak easier. I saw that he had been standing on the bare floor of the rostrum. Now this rostrum was of light wood construction and was nothing more or less than a huge drum which vibrated with every tone he uttered and gave a very disagreeable resonance. There was a large rug lying at one side of the rostrum. This was folded in four thicknesses. I had it thrown in front of the curtain, still folded. The speaker then stood on this rug and spoke and there was an enormous improvement. The speaker then walked back and forth across the rostrum speaking and the change when he stepped from the rug to the floor or the floor to the rug was so great that everyone marvelled at it. I have made experiments in several minor rooms, but they were all along the same lines.

In making a summary of the conditions necessary for the construction of an acoustically correct audience room, I find that all of the authorities agree on the main essentials.

Eugene Kelly gives the following:

First.- Construct so that the propagation of sound will be perfect in Intonation, Pitch and Timbre.

Second.- That the walls and ceiling be so constructed in their form that all returning sound waves will travel in parallel lines:- or return on their primary paths; that all conflicting or focusing walls or ceiling be constructed as dead or non-reflecting surfaces.

Third.- That the heating, ventilating and lighting apparatus be so located as to cause the entire air of the audience room to be composed of an even homogeneity, devoid of all draughts or air currents.

Fourth.- That all dead or dull speaking sound locations be reinforced by simple resonance pockets or sound reflectors, giving the entire auditorium evenly balanced volume and quality of sound.

Thomas Boyd claims that if the walls and ceilings are properly constructed in any ordinary sized audience room the acoustics will be good.

Roger Smith advises first - Avoid such dimensions as will tend to undue resonance. Avoid all arrangements and materials that may obstruct or absorb or reflect in the wrong direction.

John Faxon recommends the following essentials:

- (1) Pure air and normal temperature.
- (2) Uninterrupted transmission.
- (3) Harmonious vibration.
- (4) Minimizing of reflections.
- (5) Prevention of echoes.
- (6) Diminution of sound when the audience room is small.
- (7) Augmentation of sound when necessary.

I will close with the list of Don'ts.

Don't have undue height to the room.

Don't have a large amount of air behind the speaker.

Don't plaster solid on brick or stone walls.

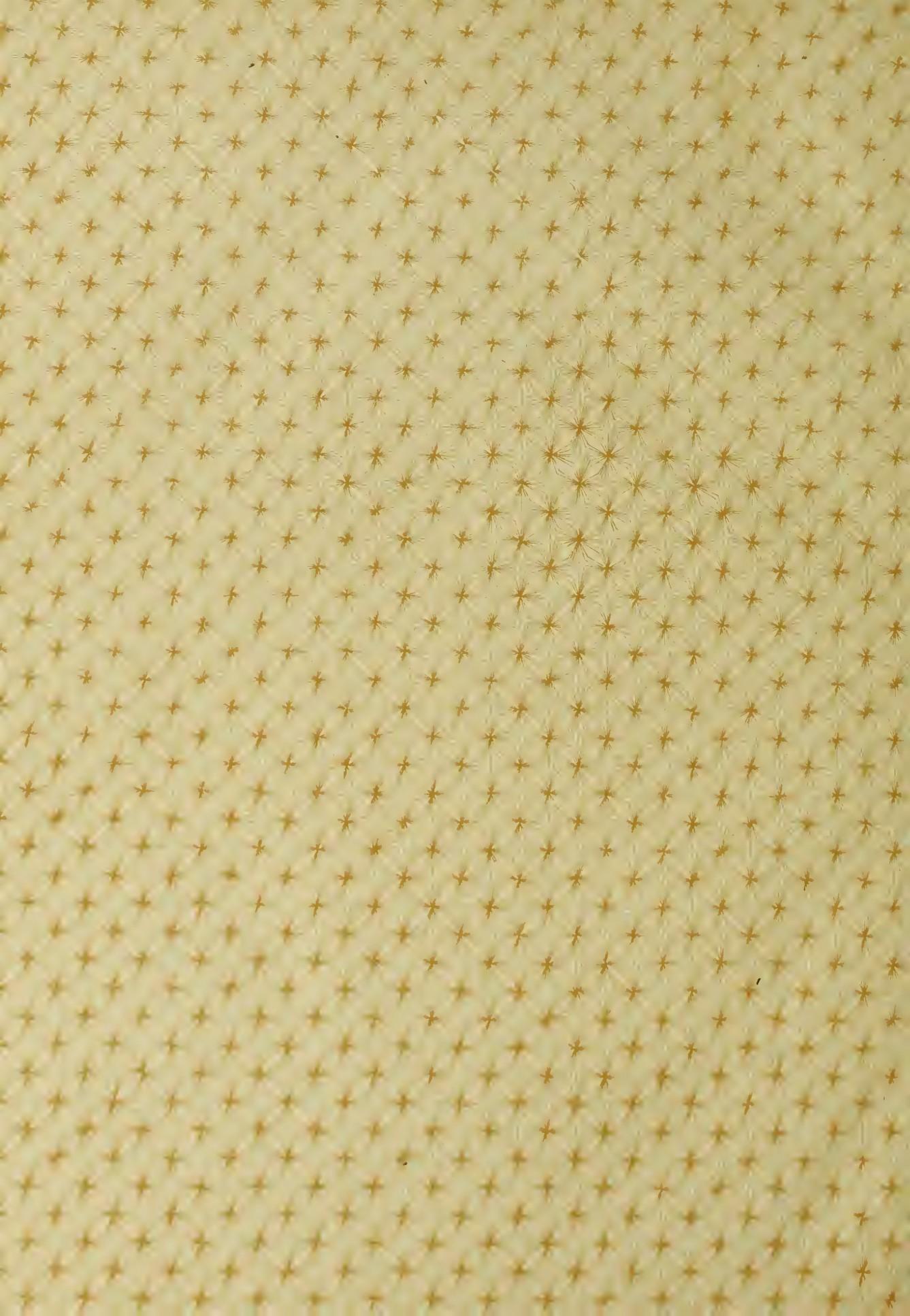
Don't use spherical or conical domes in the ceiling.

Don't build circular angles or corners to the room.

Don't supply hot air in large quantities in center of room.

Don't locate lighting in center of room; distribute it.

Don't construct large vent shaft in center of ceiling of room.





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